RESEARCH DEPARTMENT

Noise in studios from sonic booms

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RESEARCH DEPARTMENT

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SUMMARY

A brief description is given of the causes and some of the effects of sonic booms produced by supersonic aircraft. The results of measurements made during a demonstration of sonic booms have been used to show that studio roofs having an average insulation of 70 dB are probably adequate protection against sonic booms of intensities likely to be accepted in urban areas.

1. INTRODUCTION

The advent of supersonic airliners and the possibility that they may be flown over studio areas prompted a precautionary investigation of background noise in studios arising from sonic booms. The work was mainly directed towards finding out if the roof insulation criterion recently recommended by the Acoustics Committee for studios would need to be modified to cope with sonic booms as well as the noise of present-day aircraft. To assess the likelihood of sonic booms near studios, we may note that some authorities estimate that for economic reasons supersonic airliners should attain supersonic speeds within about 160 km (100 miles) of the airport. Sonic booms over heavily populated areas of Great Britain are therefore unlikely to arise from British aircraft. Air routes between the Continent of Europe and America are, however, likely to cross the country and since the boom from a high flying aircraft is audible over a corridor up to about 64 km (40 miles) wide, many parts of the country could be subjected to this nuisance.

2. THE CAUSE AND EFFECTS OF SONIC BOOMS

2.1. The Generation of Sonic Booms

A sonic boom is the audible feature of shock waves generated by an aircraft flying at supersonic speed. The leading and trailing edges of the aircraft give rise to disturbances comprising sharp rises in pressure, as depicted in Fig. 1 where the pressure distribution in the shock wave is shown near to the aircraft (Fig. 1(*a*)), at about 305 m (1000 ft) from the aircraft (Fig. 1(*b*)), and at ground level (Fig. 1(*c*))[1]. Ordinates represent over-pressure, i.e. the difference between the instantaneous air pressure and the ambient atmospheric pressure; while abscissae represent time.

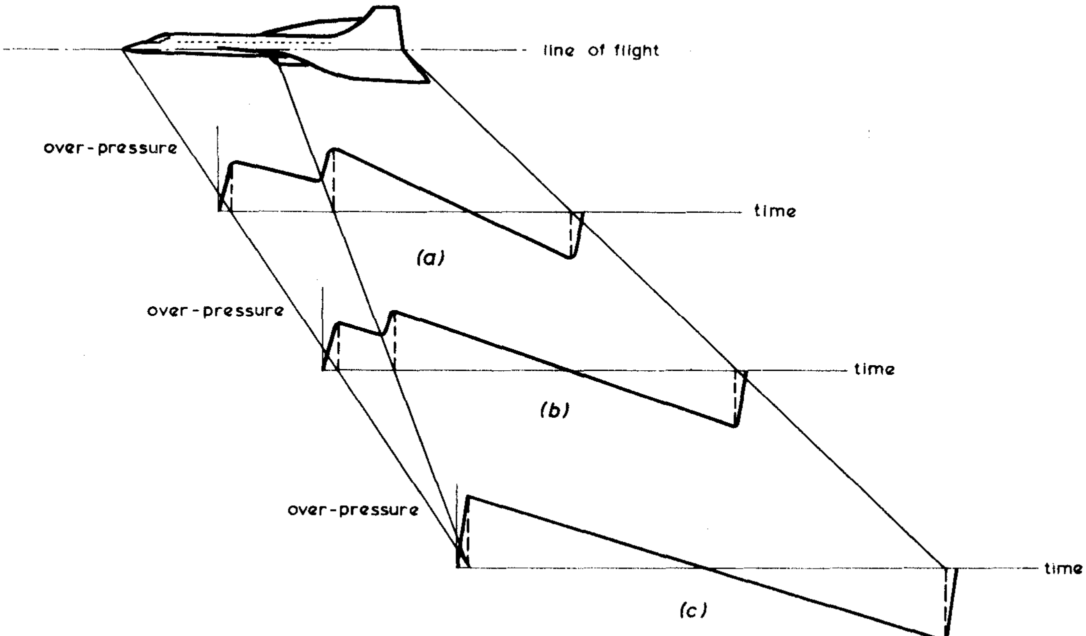

Fig. 1 - Pressure distribution in a shock wave from a supersonic aircraft

(*a*) Close to aircraft (*b*) About 305 m (1000 ft) from aircraft (*c*) At ground level

A shock wave travels at approximately the speed of sound prevailing in the region immediately in front of it, and it must therefore lie along a line making an angle with the line of flight given by $\mu = \sin^{-1}(1/M)$, where M is the Mach number, i.e. the ratio of the aircraft speed to the local speed of sound. As is shown by Wood[2], pressure disturbances of large amplitude propagate at speeds differing from the normal speed of sound, compressions travelling more quickly and rarefractions more slowly. Hence, the region of high pressure, occurring where the pressure jump at the leading edges of the wings is added to the overpressure following the bow shock wave (Fig. 1(*a*)), eventually catches up with the bow shock wave. Similarly the rarefraction at the tail lags further behind. Hence the shape of the pressure wave changes as the distance from the aircraft increases, as shown in Figs. 1(*b*) and 1(*c*).

The shape of the pressure distribution in Fig. 1(*c*) resembles an 'N' and is often referred to as an "N-Wave". It represents the basic shape of sonic boom pressure waves at ground level. Because of sundry atmospheric effects and reflections from the ground and buildings the pressure variation found in practice is seldom as simple as that shown in Fig. 1(*c*). Two examples of 'N' waves found experimentally are shown in Fig. 2 for comparison.

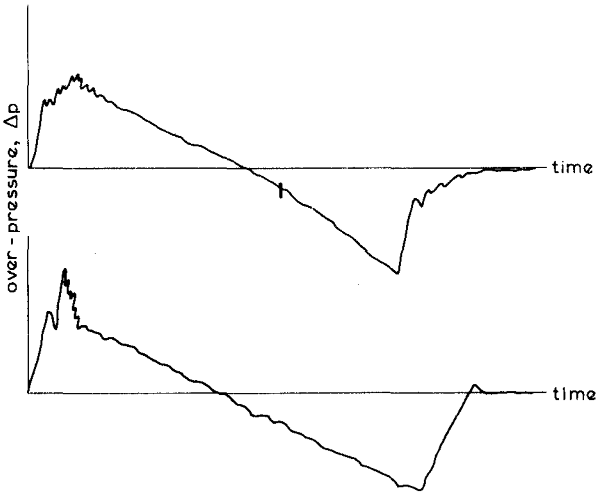

Fig. 2 - Observed pressure waves of two sonic booms

At any instant the leading and trailing shock waves from the aircraft lie approximately along a pair of cones each intersecting the ground area in a hyperbola as shown in Fig. 3. These hyperbolae sweep across the country, delineating the corridor within which a sonic boom will be heard.

For a given aircraft speed and height the duration of the 'N' wave is governed chiefly by the aircraft length; for example a 16·8 m (55 ft) long Lightning Fighter in steady level flight at Mach 1·4 and height of 9,150 m (30,000 ft) gives an 'N'-wave duration of about 120 ms while a 56·4 m (185 ft) long Concorde will probably give a duration of about 400 ms.

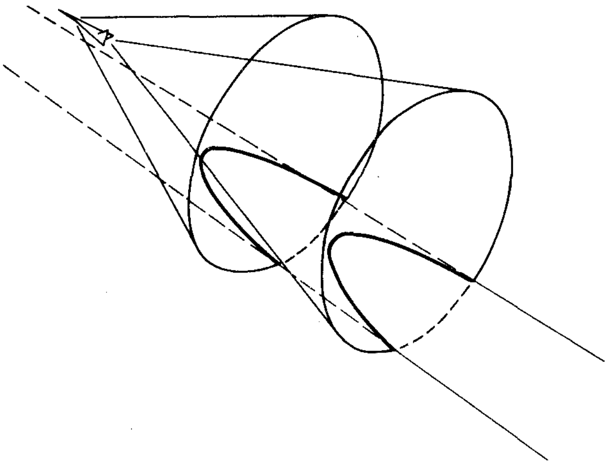

Fig. 3 - Aircraft shock waves intersect ground in hyperbolae which sweep over the ground

A useful measure of the strength of an 'N' wave is the peak over-pressure. This is basically influenced by the aircraft dimensions and weight, and is further affected by propagation through the atmosphere. The over-pressure is approximately doubled at ground level due to the summation of the incident and reflected waves. The peak over-pressure may be increased at some points distant from the aircraft by focussing of the shock wave due to turning or acceleration of the aircraft or transmission of the shock wave through a non-homogeneous atmosphere having wind or temperature gradients.

2.2. Amplitude Spectrum of an 'N' Wave

To investigate the frequency distribution of energy in a sonic boom a Fourier analysis was carried out on an ideal 'N'—wave. The 'N'—wave was treated as an isolated event and therefore possessed a continuous amplitude spectrum, the chief factors governing the energy distribution being the initial and final rise time and the total duration of the 'N'—wave. A computer programme was written to evaluate the amplitude spectrum and some of the results are shown graphically in Fig. 4. It can be seen that most of the energy is concentrated at sub-audio frequencies. The amplitude spectrum of an 'N'—wave with a rise time of 1 ms, a duration of 120 ms and a peak over-pressure of 95·8 N/m^2 (2 lb/ft^2) was integrated over octave bands to give sound pressure levels. The 'N'-wave parameters assumed here are typical of those for a Lightning aircraft in level flight at Mach 1·4 and about 9,150 m (30,000 ft) altitude. The computed results are shown in curve (*c*) Fig. 5 compared with an octave band analysis of two actual booms (curves (*a*) and (*b*)) recorded at Upwood as described in Section 3.2.

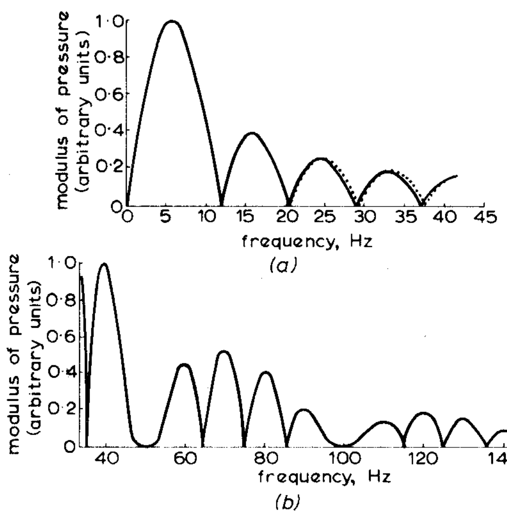

Fig. 4 - Amplitude spectra of 'N' waves of duration 120 ms

(*a*) ——— Rise time = 0 ms
·········· Rise time = 1 ms
(*b*) ——— Rise time = 20 ms

2.3. Noise, Vibration and Damage

The principal evidence which exists concerning the effects on a population exposed to sonic booms is derived from experiments in the U.S.A. and the results may not be directly applicable to Britain. Broadbent and Robinson[3] working in this country, have suggested that a sonic boom with an over-pressure of 95·8 N/m^2 (2 lb/ft^2) can be considered subjectively equivalent to aircraft noise at 110 PNdB* and may be accepted without serious protest by members of the public in urban areas.

The subjective tests carried out in the U.S.A.[4] where a mid-western town was exposed to sonic booms for a six month period, indicated a value of 102 PN dB as being equivalent to an over-pressure of 95·8 N/m^2 (2 lb/ft^2)[5]. When the series of tests began the population showed a considerable reaction based on the surprise quality of the boom and within two weeks telephone calls of enquiry or complaint were received by the local authorities at a rate of 1,700 per week. As the tests continued this number fell to a fairly steady 250 telephone calls per week and it appeared that the population had to some extent accommodated to the nuisance. The tests did not continue for a sufficient period to show whether this accommodation would continue or whether some hardening of the public attitude might build up.

Within a broadcasting organization a somewhat different attitude might be expected. In most types

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* Perceived Noise (dB): A weighted sound level whose value correlates well with noisiness.

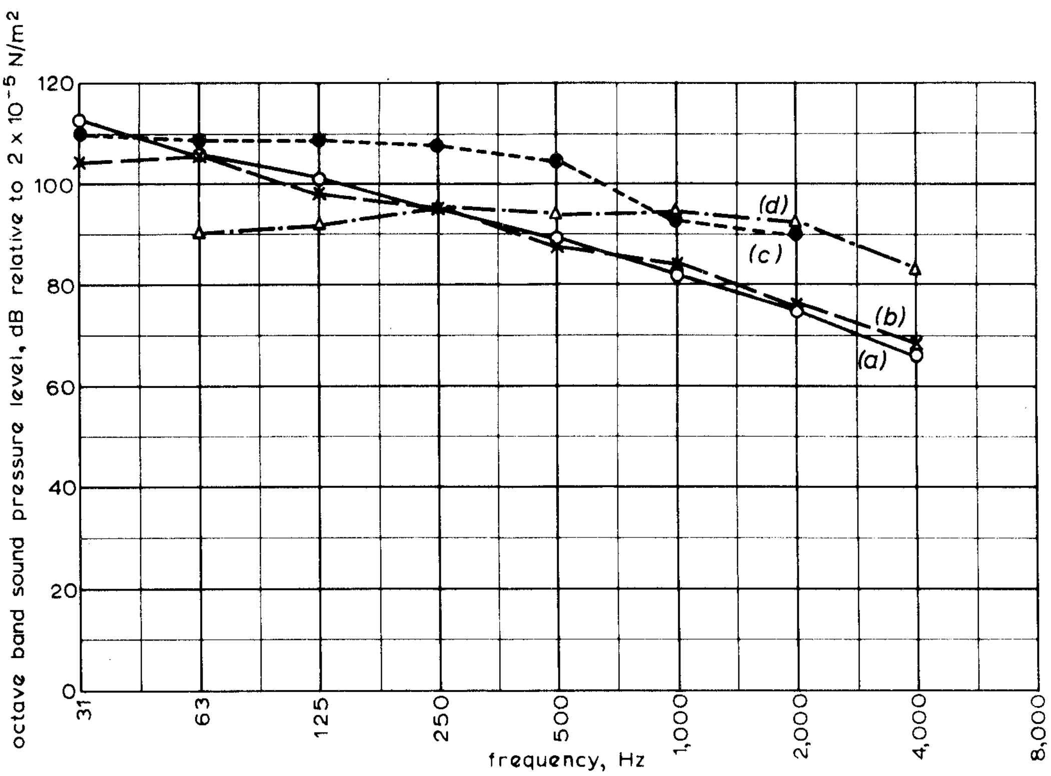

Fig. 5 - Octave band sound pressure levels

(*a*)
(*b*) } Two actual sonic booms of 95·8 N/m^2 (2 lb/ft^2) peak overpressure
(*c*) Theoretical S.P.L.'s for a 95·8 N/m^2 (2 lb/ft^2) 'N'-wave - duration 120 ms - rise time 1 ms
(*d*) Comet aircraft, 110 PN dB, measured

of programme extraneous noise, particularly if it is recognizable, is unacceptable. A particular example of this might be period drama where a noise recognizable as a sonic boom would be totally anachronistic. The investigation described in the following Sections was carried out to determine whether the boom noise levels in studios might cause disturbance, and if so, whether some increase in roof insulation might be required.

A limited amount of evidence has been gathered in this country on the effect of sonic booms on structures. It seems probable that the vibration amplitudes produced in primary structural elements are insufficient to cause damage. Even in secondary structures such as plaster-work or glass, it is unlikely that the vibrational amplitudes produced by subjectively acceptable shocks will be sufficient to cause damage unless a previous weakness exists. It may be assumed therefore that within the BBC our interest will rest entirely on the subjective effects of the shock waves.

3. MEASUREMENTS AT THE R.A.F. STATION, UPWOOD

3.1. General Description of the Tests

On 21st April 1965 a demonstration of sonic booms was arranged by the Ministry of Aviation to demonstrate to Members of Parliament and other interested parties the audible effects of sonic booms, and to compare them with the noise levels produced by a jet aircraft. Arrangements were made for a Research Department team to be present at the demonstration and to make recordings. Discussions with the Administration Officer about available Station buildings with good sound insulation resulted in a medical decontamination centre being put at our disposal. For protection against air-raid damage, this building has a heavy roof and the central room in the building is protected on each side by a series of anterooms and blast doors. The dimensions of the central room are approximately 7·6 m × 7·6 m × 3·0 m (25 ft × 25 ft × 10 ft).

The recordings were made in the central room and on the roof, the primary aims being to determine the effect, if any, of a sonic boom on programme microphones, and to measure the sound pressure levels resulting from the boom. A capacitor microphone (AKG Type C12) and a ribbon microphone (BBC Type PGS/1) were selected as being representative of two types of microphone in common use. In addition, a calibrated omni-directional moving coil microphone (S.T. and C.Type 4021) was placed in the room. A second calibrated moving coil microphone in a wind-shield was placed on the roof of the building. Accelerometer measurements were made of the vibration levels produced in the ceiling.

The flight programme consisted of six events, two flyovers by a Comet jet aircraft producing 110 PN dB, and four sonic booms producing peak over-pressures of between 60 N/m^2 (1·25 lb/ft^2) and 120 N/m^2 (2·5 lb/ft^2). This programme was performed twice during the day.

3.2. Results

No distortion due to overloading was subjectively apparent on any of the microphone outputs. The results from the ribbon and capacitor microphones were used to complement results from the moving coil microphones.

The microphone and accelerometer outputs for a representative number of the events were recorded on magnetic tape and were subsequently analysed by playing them through octave band-pass filters on to a high-speed level recorder. The tape recorders used with the microphones were of the conventional high quality audio-frequency type so that the frequency bandwidth of the broadcast programme chain was adequately covered. Special equipment for recording the whole frequency spectrum of sonic booms has been described by Taniguchi,^{6} but was not considered to be necessary for the present purpose.

The octave band sound pressure levels of two sonic booms and a Comet aircraft flyover recorded on the roof are plotted in Fig. 5 for comparison with the theoretical integrated 'N'-wave spectrum. The reasonable agreement between the theoretical and experimental curves at low frequencies provides evidence that the experimental measurements were not adversely affected by the intense low frequency energy of the sonic booms. The sound pressure levels at low frequencies are primarily determined by the peak over-pressure and duration of the 'N'-wave, for both of which there was good agreement between the theoretical and experimental pressure waves. Agreement above about 100 Hz (c/s) should not be expected because atmospheric and ground conditions rarely allow an ideal 'N'-wave to be observed. Rounding of the peaks and other deviations from the idealized 'N'-wave give rise to the gentle slope of the measured spectra as compared with the relatively sharp drop in the theoretical spectrum above a frequency of about 1 kHz corresponding to the rise-time of 1 ms. It is of interest to compare the 95·8 N/m^2 (2 lb/ft^2) sonic boom spectra with that from a Comet aircraft with a weighted sound level of 110 PN dB, although the subjective annoyance may not be directly related to the pressure spectrum. It seems probable that the higher noise levels at high frequencies from aircraft engines are subjectively balanced by the higher pressures at low frequencies from sonic booms.

The accelerometer measurements were not comprehensive but the measured accelerations did not exceed an acceptable value (about 0·01 m/s^2).

It has been found that measurements with a continuous noise such as that from a jet engine correspond closely to standard measurements of sound insulation and give results in good agreement with laboratory tests. Fig. 6 shows the values of sound level reduction from outside to inside the decontamination centre using the measured sound pressure levels of jet engine noise and sonic boom. Above 500 Hz the values derived from sonic boom sound pressure levels are considerably reduced. The possibility that the effective sound level reduction at frequencies of 1 kHz and above is lower for shock excitation than for continuous excitation must therefore be considered. No evidence to support this suggestion has been found heretofore, and measurements of sound insulation made with a 0·45 in. (11 mm) calibre revolver have agreed well with conventional measurements. It will be shown later however that the effect is not significant in this investigation.

4. THE RELATIONSHIP BETWEEN THE MEASUREMENTS AND BBC PRACTICE

4.1. Synthesis of Sonic Boom Sound Pressure Levels (S.P.L.'s) inside a Television Studio

The type of studio most susceptible to interference from aircraft noise or sonic booms is that having a large area of roof not screened by surrounding buildings or natural obstacles. Consequently considerable attention has been paid to the sound level reduction required of studio roofs. The presently proposed standard of studio roof insulation is shown in Fig. 6. A studio with a roof conforming precisely to this standard is said to have a "70 dB roof", 70 dB being approximately the average value of sound level reduction between 100 Hz and 3200 Hz.

To assess the interference that a sonic boom would cause if it occurred during a drama production, especially during a quiet moment of tension, an estimate was made of the noise spectrum that might occur within a studio having a 70 dB roof. Taking the S.P.L.'s of one of the sonic booms recorded at Upwood as representative of those likely to prevail above the studio roof, the levels inside the studio (Fig. 7) were obtained by subtracting at each frequency the sound level reduction for a 70 dB roof. Fig. 7 shows that the noise inside a studio would be negligible at frequencies above about 500 Hz and this conclusion remains true even if allowance is made for uncertainty about the effective insulation at high frequencies under shock wave excitation, to which reference was made in Section 3.2 above.

The greatest noise excess above the permissible level is shown in Fig. 7 to be 11 dB in the 125 Hz octave band. This level is probably not high enough to interfere seriously with programme even if it occurs in a moment of quiet provided that it occurs infrequently, as is most likely.

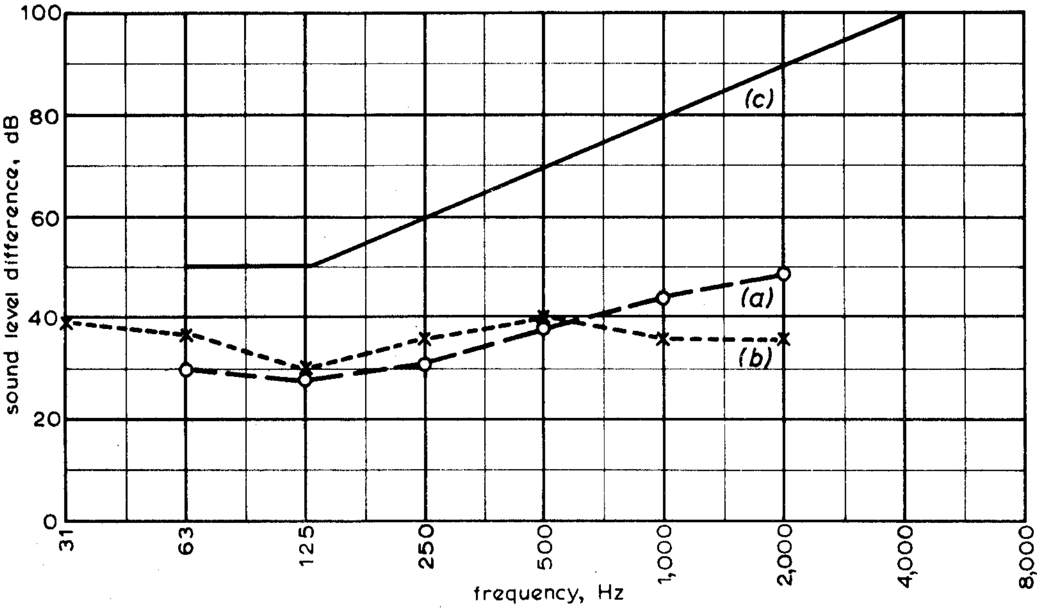

Fig. 6 - Sound level differences

(*a*) Decontamination centre, Upwood. Measured with jet engine noise
(*b*) Decontamination centre, Upwood. Measured with sonic booms
(*c*) Proposed insulation for studio roofs

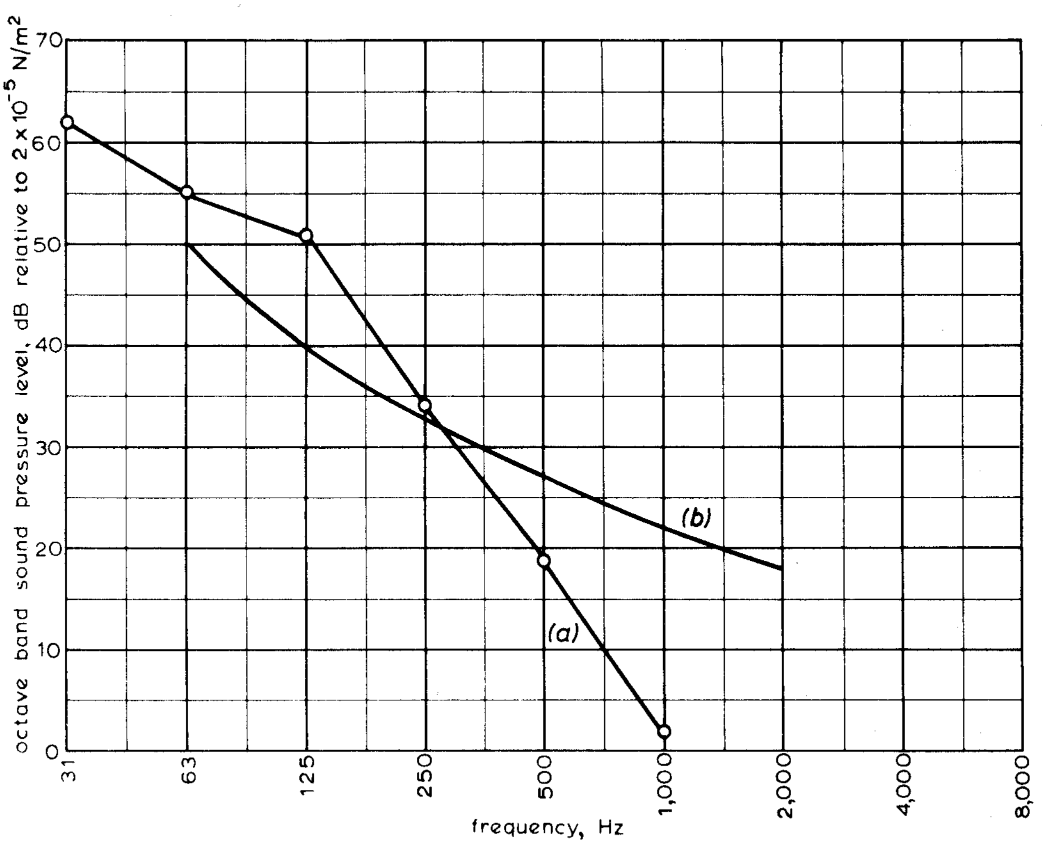

Fig. 7 - Octave band sound pressure levels

(*a*) Estimated S.P.L. of 95·8 N/m^2 (2 lb/ft^2) sonic boom inside a television studio
(*b*) Permissible background noise inside a television studio

4.2. Demonstration Recording

To facilitate the communication of the essential results to interested people a recording was prepared for subjective assessment. The recording demonstrated sonic booms and a jet flyover on the one hand and on the other hand it included the noise of sonic booms attenuated as if by a roof and superimposed on an excerpt from a television play. Emphasis was laid on the programme interference caused by the sonic booms.

The procedure adopted in preparing the drama excerpt was as follows:

(a) A recording was obtained of a television drama production made in a studio with a background noise approximating to the appropriate characteristic curve of maximum permissible noise;

(b) it was felt that the listener would probably be annoyed to the greatest extent when a sonic boom occurred during a tense dramatic sequence. Excerpts were accordingly chosen to represent this type of sequence;

(c) the recording of a sonic boom made inside the building at Upwood was played through a variable filter unit to make its spectrum approximately that of a boom as heard inside a studio with a 70 dB roof (see Fig. 7);

(d) the modified boom recording was dubbed on to the drama excerpt at appropriate moments. The ratio of the boom level to the background noise level in the drama excerpt was arranged to be the same as the ratio of a 95·8 N/m^2 (2 lb/ft^2) boom level, attenuated by a 70 dB roof, to the maximum permissible background noise level for television studios (see Fig. 7).

In order to enhance the realism of the demonstration care was taken when the final recording was replayed to make the audible sound pressure levels in the listening room, for the sonic boom and jet aircraft flyover, approximately equal to the ground level open-air values. Conventional high quality audio-frequency reproduction equipment was used and consequently, although the full subjective effects of the boom and flyover were not reproduced, a large enough frequency band was represented for assessing the effects on broadcasts. The television drama excerpts were replayed at about the mean listening level adopted by BBC engineers.[7]

The final recording was demonstrated to the BBC Acoustics Committee and to other interested parties. The general reaction is that the interference with programme caused by a 95·8 N/m^2 (2 lb/ft^2) sonic boom is not serious when the studio has a 70 dB roof, and that no special precautions need be taken against sonic booms at the moment so far as studios are concerned.

5. CONCLUSIONS

(1) If commercial supersonic flight becomes general, sonic booms will probably be experienced in most parts of the country, mainly from air routes between North America and the Continent of Europe.

(2) Legislation is likely to impose an upper limit of 95·8 N/m^2 (2 lb/ft^2) on the permitted over-pressure at ground level from such aircraft.[5]

(3) If the above two conclusions are borne out in practice, a mean roof insulation of 70 dB as proposed by the Acoustics Committee should be sufficient to avoid interference on programmes, provided the upper limit of over-pressure is strictly observed.

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